Astrometry of Red Supergiant VY Canis Majoris with VERA

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We present results of multi-epoch VLBI observations of 22 GHz H_2O and 43 GHz SiO masers (v=1 and 2 J=1−0) in red supergiant VY Canis Majoris (hereafter, VY CMa) for 13months with VERA (VLBI Exploration of Radio Astrometry). An extragalactic source J0725−2640, whose angular separation is 1.059 degrees from VY CMa, has been observed simultaneously as a phase-reference source with VERA dual-beam system. As results of phase-referencing analysis, we have estimated the annual parallax of VY CMa to be 0.866±0.075 mas, corresponding to the distance of 1.15 ±0.10 kpc from the Sun. We also confirmed the method which uses a maser spot as a phase-reference s ource to detect a weak continuum source. As a result, it is possible to superpose the maps of the H_2O masers and the v=1 and 2 J=1−0 SiO masers.

VY Canis Majoris

- One of the brightest red supergiants
- Asymmetric nebula combined with high mass loss rate
- Mass-loss rate: 3×10^{-4} $M_\odot$ yr^{-1} (Danchi et al. 1994)
- Distance: d = 1.5 kpc (Lada & Reid 1978)
- Luminosity: L = 5×10^5 $L_\odot$ (Humphreys & Davidson 1994)
- Effective temperature: T_{eff} = 2800 K (Monnier et al. 1999)
- Expected mass based on theoretical models: M ∼ 25$M_\odot$ (Chieffi et al. 1998)
- One of the most important stars for understanding the high mass loss episodes near the end of massive star evolution

Observations

- Multi-epoch VLBI observations with VERA dual-beam system
  H_2O: DOY 114, 144, 245, 303, 331 in 2006, 010, 045, 085, 111, 147 in 2007
  SiO (v=1 and v=2 J=1−0)
  : DOY 113, 146, 220, 246, 304, 332 in 2006, 007, 046, 084, 110, 147 in 2007
- Target: H_2O masers, v=1 J=1−0 and v=2 J=1−0 SiO masers in VY CMa
  Reference source: J0725−2640 (the separation angle is 1.059 degrees)
- Beam size: 2.1 mas × 0.8 mas (H_2O) and 1.2 mas × 0.4 mas (SiO)
- Recorded with 16 MHz x 16 IF channels :
- Correlation: the Mitaka FX correlator
- The velocity resolution: 0.21 km s^{-1}.
- All data reduction were performed with AIPS software.

The distance to VY CMa

We measured the annual parallax of VY CMa by multi-epoch VLBI astrometry.
Fig. 1 shows the parallax fit for the H_2O maser spot whose LSR velocity is 0.55 km s^{-1}.
→ Best fit for R.A.: π = 0.866±0.075 mas, corresponding to the distance of 1.15 ± 0.10 kpc.
Proper motion : −2.09 mas yr^{-1} in R.A. and 1.02 mas yr^{-1} in DEC

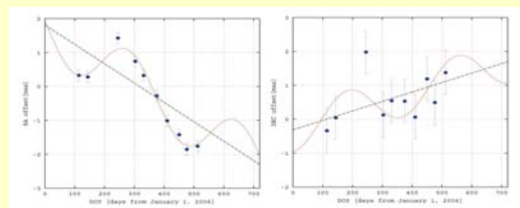

Figure 1. Results of the position measurements of the H_2O maser spot at the LSR velocity of 0.55 km s^{-1} in VY CMa. **(left)** The movement of the maser spot in R.A. as a function of time for 13 months. **(right)** The same as (left) in DEC. Solid lines represent the best fit model with the annual parallax and linear proper motion for the maser spot. Dotted lines represent linear proper motion (−2.09 mas yr^{-1} in R.A. and 1.02 mas yr^{-1} in DEC) and the points represent the observed positions of maser spot with error bars indicating the standard deviations of the least-squares analysis (0.10 mas in R.A. and 0.42 mas in DEC).

The Spectra and the distributions of the H_2O masers and the SiO masers

Fig. 2 shows the spectrum and the distribution of the H_2O masers.
The center of the map is 07h22m58.32906s in R.A.(J2000) and −25d46'03.1410" in DEC(J2000) and the maser features are distributed in 400 mas × 400 mas (460 AU × 460 AU at 1.15 kpc).
Fig. 3 shows the spectra and the distributions of the v=1 and v=2 J=1−0 SiO masers.
The v=1 J=1−0 SiO masers are distributed in 70 mas × 100 mas (80 AU × 115 AU at 1.15 kpc).
The v=2 J=1−0 SiO masers are distributed in 30 mas × 40 mas (35 AU × 46 AU at 1.15 kpc).

The Superposition between H_2O masers and SiO masers

There is a good positional agreement between a phase-referencing method using a continuum source as a phase reference source and an inverse phase-referencing method using a maser spot as a reference with the accuracy of 30 μas. We successfully detected the a continuum source J0725-2640 at 43 GHz with a SiO maser spot as a phase-reference source. As a result, we can show the superposed map. (Fig. 4)

The Kinematics of H_2O maser features

We estimated the absolute linear proper motion for each H_2O maser feature and subtracted the average motion (−3.58 mas yr^{-1} in R.A. and 2.93mas yr^{-1} in DEC). (the red arrows in Fig. 4)

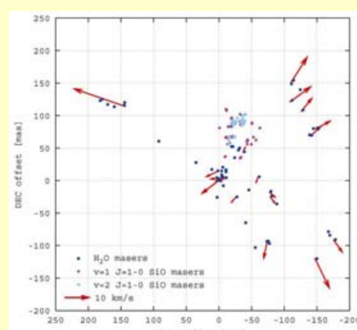

Figure 4. The superposed map of the H_2O masers (blue points), the v=1 J=1−0 SiO masers (pink points), the v=2 J=1−0 SiO masers (cyan points). The red arrows represent the absolute motions, which the average motion was subtracted, for the H_2O maser features. The average motion is −3.58 mas yr^{-1} in R.A. and 2.93mas yr^{-1} in DEC, respectively. 1 mas yr^{-1} corresponds to 5.5 km s^{-1} at the distance of 1.15 kpc.

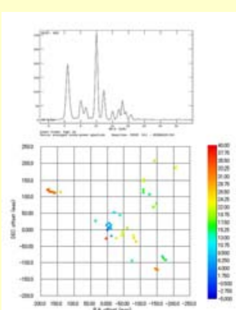

Figure 2. (top) An example of cross power spectrum of the H_2O masers in VY CMa observed with the VERA Mizusawa-Iriki baseline (1267 km).
(bottom) The distribution of the H_2O masers in VY CMa. Both are observed on April 24, 2006.

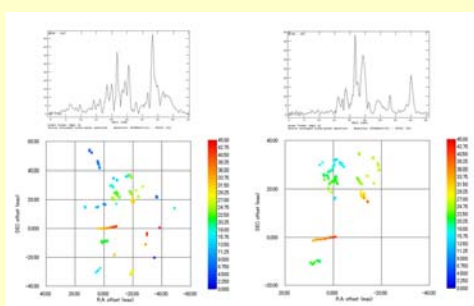

Figure 3. (left) The top panel is an example of cross power spectrum of the baseline between Mizusawa and Iriki (1267 km) and the bottom is the distribution of the v=1 J=1−0 SiO masers in VY CMa observed on April 20, 2007. **(right)** The same as (left) for the v=2 J=1−0 SiO masers.

Future works

- Additional phase-referencing analysis to get more accurate value of the annual parallax with another H_2O maser spots
- The measurement of the annual parallax and proper motion for v=1 and v=2 J=1−0 SiO masers
- Detailed modeling for the kinematics of the circumstellar envelope of VY CMa